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An HSUS Report: Human Health Implications of U.S. Live Bird Markets in the Spread of Avian Influenza

The Humane Society of the United States

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Abstract

After millions of years of existing as a harmless infection of aquatic birds, some strains of avian flu have developed the ability to mutate into highly pathogenic forms that may not only be deadly for birds, but potentially more dangerous for humans as well. Experts from the World Health Organization, the World Organization for Animal Health, and the Food and Agriculture Organization of the United Nations have joined leading scientists in implicating industrialized poultry production for providing fertile ground for the transformation of benign bird flu into highly pathogenic strains.

Live bird markets can be the conduit by which waterfowl viruses enter into industrial poultry populations and have been identified as playing a critical role in the emergence of H5N1, a deadly strain of avian influenza threatening to trigger a human flu pandemic. In response, Asian countries are shutting them down. In the United States, live bird markets have been tied to domestic outbreaks of highly pathogenic avian influenza and have been described by U.S. Department of Agriculture poultry researchers as the "missing link in the epidemiology of avian influenza,"[1] yet hundreds of these retail storefront slaughter markets still operate across the country, processing tens of millions of birds annually.

Background on Avian Influenza

The primordial source of all influenza viruses—avian and mammalian—is aquatic birds.[2] In nature, the influenza virus has existed for millions of years as a harmless, intestinal, waterborne infection of waterfowl, particularly ducks,[3] who are infected as ducklings. Studies of ducks on Canadian lakes show that up to 30 percent of juvenile birds are actively shedding the virus.[4] The birds excrete such massive titers of virus[5] that researchers have been able to culture it straight out of a spoonful of lake water.[6] Under the right conditions, the virus is estimated to be able to persist for years in cold water.[7] With such high concentrations of virus and its highly efficient transmission[8] and environmental stability, scientists estimate that virtually all of the millions of ducks in the world become infected sometime during their lives.[9]

Avian influenza multiplies in the ducks' intestinal lining and is then excreted into the water of ponds, lakes, and other reservoirs. Ducks touching down to drink ingest the virus, and the cycle continues as it has for perhaps 100 million years before the first person became infected with the flu.[10] The ducks are not infected for long;[11] most only shed virus for a few days. However, the fecal-oral route of infection for aquatic birds is so efficient that this narrow period of contagion is thought to be enough to keep the virus spreading throughout the millennia.[12] Millions of years of evolution have so tailored the parasite to its host, a so-called "optimally adapted system," that the virus seems completely innocuous to the ducks.[13] The virus exists in an "evolutionary stasis" in waterfowl,[14] remaining unchanged despite its rapid mutation rate.[15]

Influenza viruses do not tend to retain any new mutations in ducks because they found their perfect niche. Sharks, for example, have remained basically unchanged for 100 million years, even while other species evolved around them, presumably because sharks had already evolved to be such perfected predators.[16] Similarly, evolution has not seemed able to significantly improve influenza. While the virus continues to mutate to achieve greater and faster spread, the virus-duck relationship seems so cooperative that any deviant viral progeny are less successful and die out. The virus has achieved peak efficiency and is found ubiquitously throughout aquatic bird species around the world.[17]

As the influenza virus in its natural state is so finely attuned to its aquatic host, it not only doesn't harm the carrier duck, but it also seems unable to cause serious disease in humans. Before the emergence of H5N1, the deadly mutant strain of avian influenza spreading out of Asia, there had been only two reports of human infection from wild bird viruses in the medical literature: one involving a woman who kept ducks and got a piece of straw caught in her eye while cleaning out her duck house,[18] and the second of a laboratory field worker whose eye was sneezed into by a bird flu-infected seal.[19] Despite direct inoculations of virus, the result was limited to a mild, self-contained (unspreading) case of conjunctivitis, commonly known as pinkeye.[20]

Scientists have been relatively unsuccessful in attempts to directly infect human volunteers with waterfowl viruses. Test subjects snorted massive doses of virus—enough to infect up to a billion birds—yet, most of the time, did not become infected themselves. When the virus did have an effect, it typically produced nothing more than a transitory local reaction.[21] The evolutionary gulf between duck gut and human lung is so broad that an intermediate host is thought to be needed to act as a stepping stone for the virus.[22] "And poultry," said a spokesperson for the Department of Homeland Security's National Center for Foreign Animal and Zoonotic Disease Defense, "are likely to be that host."[23] Bird flu viruses only "heat up," in the words of Dutch virologist Albert Osterhaus, "when they pass from wild birds to poultry."[24]

Mutation

All bird flu viruses begin as mild, low-grade, low-pathogenicity avian influenza (LPAI) viruses. H5 and H7 virus strains, however, have the potential to mutate into high-grade "fowl plague" viruses, now known as HPAI—highly pathogenic avian influenza.

In its 2005 assessment of the pandemic threat, the World Health Organization explained the emergence of HPAI viruses: "Highly pathogenic viruses have no natural reservoir. Instead, they emerge by mutation when a virus, carried in its mild form by a wild bird, is introduced to poultry. Once in poultry, the previously stable virus begins to evolve rapidly, and can mutate, over an unpredictable period of time, into a highly lethal version of the same initially mild strain."[25]

Live bird markets have been identified as enabling the introduction of low-grade, waterfowl avian influenza viruses to commercially reared poultry. Consider the following scenario: An infected duck is transported to a live poultry market where a variety of bird species are typically confined in cages stacked in tiers. The duck's droppings fall outside the wire enclosure onto other birds, customers and workers, and the surrounding environment. Direct human contact with the infected feces may not result in the unmutated duck virus taking hold. However, terrestrial birds, such as quail and chickens, two species commonly found at live bird markets, are not natural hosts for influenza,[26] yet may be recognizable enough by the virus to become infected. Despite this, the influenza virus, finely attuned to ducks and other waterfowl and having remained in total evolutionary stasis in aquatic birds,[27] must mutate to survive and effectively spread in, for example, the gut of a chicken. The influenza can no longer remain a strictly waterborne virus. Although it can still spread through feces when chickens peck at each other's droppings, the virus must, for example, resist dehydration better in the open air[28] and presumably adapt to the novel body temperature and pH of its new environment.[29]

In ducks, the virus relies on a healthy host for its spread and seems to have evolved a mechanism that allows the virus to replicate only in the intestine, so as not to infect other tissues and potentially harm the carrier. However, in such foreign environments as land-based poultry, influenza—highly effective at mutating[30]—quickly begins to try to adapt to the new host[31] in order to survive.[32,33] Given adequate time and numbers of hosts within which to mutate, some bird flu viruses are able to learn how to invade other organs, such as the lungs, through which to travel.

Evolved Harmlessness and Transitioning Virulence

Before the virus can become infectious, a protein spike in its viral coat called hemagglutinin (the "H" in H5N1) must first be cleaved in half to become activated. This cleavage is done by specific host enzymes found only in certain tissues, including the intestinal tract. The limited bodily distribution of the specific cleavage enzyme restricts the virus to safe areas such as the duck's gut, preventing it from replicating in the brain or other vital organs. This restriction, evolved harmlessness, has allowed influenza to most effectively pass on and spread its genes.[34] Yet, once the virus successfully infects an unfamiliar species, this may no longer be the case. Researchers have shown that H5N1 seemed to enter chicken populations as an intestinal virus but left as more of a respiratory virus.[35]

Once a foreign host is infected, the virus must not only find new ways to spread; it must also overcome a hostile immune response. Under these circumstances, viral progeny that eliminate the fail-safe mechanism that restricts it to the gut may outspread others and be naturally selected. The hemagglutinin spike of H5 and H7 viruses can mutate over time to be activated by enzymes in any organ in the body, allowing the virus to essentially liquefy the bird from the inside—the "flubola" phenomenon of highly pathogenic avian influenza.[36] While influenza remains harmless to its waterfowl hosts in its natural state, the virus can be forced into what evolutionary biologists call an "acute life strategy" in which its only choice may be to rapidly overwhelm the host to gain entry and survive in new environments.[37] Viral mutants with diminished lethality may have an overall advantage over strains that kill the host too quickly, thereby limiting the opportunities for infectious spread, since the host may stay alive longer and have more occasion to pass on the virus. Natural selection mediates this evolutionary process, choosing over time the virus with the perfect balance of lethality and contagion.[38] However, transitions are not always toward lesser virulence.[39]

Infecting an unfamiliar host such as a chicken, the influenza virus may become as virulent as possible to overpower the bird's defenses.[40] In a natural setting, if the virus kills the chicken too quickly, it may not be able to infect many others. Yet, in unnatural settings such as those common in intensive poultry production where tens of thousands of genetically similar birds are intensively confined in a single enclosure, there may be fewer limits to how virulent certain influenza viruses can become and still survive.

Mutation Facilitation by Industrial Poultry Production

Scientists have demonstrated the transformation of viruses from harmless to deadly in a laboratory setting. A collaboration of U.S. and Japanese researchers started with H5N3, a harmless virus isolated from a whistling swan, unable to infect a healthy, adult chicken. The researchers proceeded to do serial passages through baby chickens, squirting a million infectious doses into the lungs of day-old chicks. The virus would presumably start to adapt to the chicks' respiratory tracts, with the viral mutant that most effectively and efficiently overcame the hatchlings' defenses selected to predominate. After three days, the scientists killed the chicks, ground up their lungs, and introduced this infectious material down the throats of other chicks. They again allowed a few days for the virus to adapt further before repeating the cycle two dozen times.

When the last set of chicks was killed, the researchers ground up their brains instead of their lungs and infected five additional rounds of healthy chicks with the brain pulp. With every passage, the virus grew more adept at overwhelming the fledging birds' immune systems to best survive and thrive in its new environment. After two dozen cycles though lungs and five cycles through brain, the final infected brain sample was squirted into the nostrils of healthy, adult chickens. Although the original H5N3 swan virus was unable to infect the chickens, by the 18th lung passage, the strain was able to kill half of the chickens exposed. After the final five brain passages, the virus was capable of rapidly killing every one. The researchers concluded: "These findings demonstrate that the avirulent [harmless] avian influenza viruses can become pathogenic during repeated passaging in chickens."[41]

Industrial poultry production settings allow for the potential of tens of thousands of such serial passages in a single building. The World Organization for Animal Health (OIE) and the Food and Agriculture Organization of the United Nations (FAO) agree that it has been "prove[n]"[42] that once LPAI viruses gain access to poultry facilities, they can "progressively gain pathogenicity in domestic birds through a series of infection cycles until they become HPAI."[43] However, deadly bird flu viruses do not tend to arise in merely any poultry operation. According to U.S. Department of Agriculture researchers, it is the "high density confinement rearing methods" that give bird flu "a unique chance to adapt to the new species."[44] That is, today's intensive animal production practices may remove the natural obstacles to transmission that prevent the virus from becoming too dangerous.

Director of the USDA's chief poultry research laboratory and the agency's leading bird flu expert, David Swayne has authored more than 100 scientific publications on avian influenza.[45] According to Swayne, there has never been a recorded emergence of an HPAI virus in any backyard flock or free-range poultry operation. If a wild duck were to excrete a dropping laden with a relatively innocuous virus into a free-range flock, the chickens may be exposed to the virus, but coming straight from waterfowl, the virus is so finely tuned to duck physiology that it may not gain a foothold before being killed by a healthy chicken's immune system. This is why in the laboratory, researchers *injected* infected lung tissue from one bird to another to facilitate transmission. "The conditions under which we generated highly virulent viruses from an avirulent strain are generally not duplicated in nature," the research team acknowledged. "However, viruses with low pathogenicity can cause viremia in physically compromised chickens."[46] Viremia means successful invasion of the bloodstream by the virus, an incursion they deem more likely to occur in compromised hosts.

If an outdoor flock does become infected, the virus must continue to spread to remain in existence. Influenza virus, a waterborne virus, is rapidly killed by sunlight and tends to dehydrate to death in the breeze. Its ability to spread efficiently from one chicken to the next while outdoors in the open air is relatively limited. In a sparsely populated free-range setting, there may simply be too few susceptible hosts nearby to passage between in order to build up enough adaptive mutations to evolve into a highly pathogenic form. According to bird flu expert Dennis Alexander of the U.K.'s Central Veterinary Laboratory, highly pathogenic influenza viruses have "never known to arise in an outdoor [chicken] flock."[47]

In contrast, the conditions and practices of industrial chicken production are considered to be optimal for dangerous viral mutations.[48] Industry trade journal *World Poultry* listed some factors that make intensive poultry facilities such "ideal"[49] "breeding grounds for disease"[50]: "poor ventilation, high stocking density, poor litter conditions, poor hygiene, high ammonia level, concurrent diseases and secondary infections."[51] Indeed, an avian virology textbook states: "Viral infections can move fastest through groups of birds maintained in closed, crowded, unsanitary conditions."[52] Frederick Murphy, dean emeritus of the School of Veterinary Medicine at the University of California-Davis, has noted how intensification in farm animal production practices "often allow[s] pathogens to enter the food chain at its source and to flourish, largely because of stress-related factors."[53] The physiological stress created by crowded confinement can have a "profound" impact on immunity,[54] predisposing animals to infection.[55] Diminished immune function reduces protective responses to vaccinations. "As vaccinal immunity is compromised by factors such as…immunosuppressive stress," writes a leading[56] USDA expert on chicken vaccines, "mutant clones have an increased opportunity to selectively multiply and to be seeded in the environment."[57] Studies exposing birds to stressful housing conditions provide "solid evidence in support of the concept that stress impairs adaptive immunity in chicken."[58]

Typical broiler chicken production practices entail intensively confining tens of thousands of genetically undiverse[59] birds in massive, unhygienic warehouses, standing and lying in their own excrement. The high stocking densities of commercial poultry production result in an extraordinary amount of waste, and as influenza can survive in wet manure for weeks, these unhygienic conditions pose significant risk. A 20,000-bird broiler chicken flock produces more than a ton of droppings every day.[60] And, according to the USDA, a single gram of manure (approximately the weight of a paper clip) from an infected chicken can contain "enough virus to infect 1 million birds."[61]

Moist fecal dust and ammonia in the air irritate the birds' respiratory passages, further increasing susceptibility in chickens already compromised by the stress of confinement. Feces decomposition generates several irritating chemicals, including hydrogen sulfide, methane, and ammonia,[62] which "in a poultry house is nauseating to the caretaker, irritates the eyes, and affects the chickens," states one poultry science textbook.[63] Given the extreme stocking density of intensive production facilities, the litter can get so saturated with excrement that birds may develop sores or "ammonia burns" on their skin, known as breast blisters, hock burns, and footpad dermatitis, all of which have become significantly more common and serious over the last 30 years.[64]

Studies have shown that high levels of ammonia also increase the severity of respiratory disorders, such as pneumonia,[65] in part by directly damaging the respiratory tract, predisposing birds to infection.[66] A large-scale study of millions of birds from nearly 100 commercial farms across multiple countries found that ammonia levels increased the excretion of the stress hormone corticosteroid, a potent immune depressant.[67]

Since the birds are standing in their own excrement, the virus need not even develop true airborne transmission via nasal or respiratory secretions. Rather, the virus has an opportunity to be excreted in the feces and then inhaled or swallowed by the thousands of other birds confined in the shed, allowing the virus to circulate rapidly and repeatedly.

Industrial Poultry Production Implicated by Global Experts

The World Health Organization (WHO), the OIE, and the FAO, respectively the world's leading medical, veterinary, and agricultural authorities, all implicate industrial poultry production as playing a role in the current avian influenza crisis. The WHO blames the increasing trend of emerging infectious diseases in part on the "industrialization of the animal production sector"[68] in general, and the emergence of H5N1 on "intensive poultry production" in particular.[69] The OIE blames in part the shorter production cycles and greater animal densities of modern poultry production, which result in a "greater number of susceptible animals reared per given unit of time."[70] Said one senior FAO official, "[I]ntensive industrial farming of livestock is now an opportunity for emerging diseases."[71]

Other experts around the world similarly lay blame at least in part on "so-called factory farming,"[72] "intensive poultry production,[73] "large industry poultry flocks,"[74] "intensive agricultural production systems,"[75] or "intensive confinement."[76] "We are wasting valuable time pointing fingers at wild birds," the FAO has stated, "when we should be focusing on dealing with the root causes of this epidemic spread which…[include] farming methods which crowd huge numbers of animals into small spaces."[77]

In October 2005, the United Nations issued a press release on bird flu specifically calling on governments to fight what they call "factory farming": "Governments, local authorities and international agencies need to take a greatly increased role in combating the role of factory-farming, commerce in live poultry, and wildlife markets which provide ideal conditions for the virus to spread and mutate into a more dangerous form…."[78]

Emeritus professor Kennedy Shortridge, the virologist who first characterized H5N1 in Asia, was awarded the highly prestigious Prince Mahidol Award in Public Health, considered the "Nobel Prize of Asia,"[79] for his pioneering work on H5N1.[80] From 1977 to 2002, he advised the World Health Organization on the ecology of influenza viruses.[81] Shortridge described how modern poultry operations have created the greatest risk scenario in history. "The industrialization is the nub of the problem," he said. "We have unnaturally brought to our door-step pandemic-capable viruses. We have given them the opportunity to infect and destroy huge numbers of birds and…jump into the human race."[82] Johns Hopkins neurovirologist R.H. Yolken and Stanley Medical Research

Institute director E.F. Torrey agree: “In our efforts to streamline farming practices to produce more meat for more people, we have inadvertently created conditions by which a harmless parasite of wild ducks can be converted into a lethal killer of humans.”[83]

The Role of Live Bird Markets

Analyzing the genome of H5N1, scientists now suspect that its original 1997 Hong Kong outbreak arose when an H5 goose virus combined with an N1 duck virus with quail acting as the mixing vessel. The virus then jumped from quail to chickens and then from chickens to humans.[84] Cross-contamination at live bird markets is the likely explanation of how these viruses jumped from species to species and, ultimately, farm to farm.

According to expert Professor Shortridge, live bird markets are an “avian influenza melting pot.”[85] Animals sold live guarantee freshness in the minds of some consumers, but the conditions of typical storefront slaughter facilities are unhygienic and severely compromise the animals’ well-being: animals cough and defecate over one another, spewing potential pathogens throughout the market;[86] chickens, ducks, geese, quail, and other birds are confined into restrictive cages stacked in tiers as much as five high, with distressed birds defecating on those below them;[87,88] and feathers and feces,[89] as well as blood and intestines[90] soil the market. According to the WHO, the birds are often slaughtered on the spot, “normally with very little regard for hygiene.”[91] “The activities of humans have affected the evolution of influenza,” reads a 2004 Cambridge University Press textbook on pathogen evolution, “but not to our advantage. Close confinement of various strains of fowl in live poultry markets provide conditions ripe for the formation of new reassortment viruses and their transmission to humans.”[92] “If you have seen these markets, you know that the birds are under stressful conditions,” said a veterinarian with New York’s Department of Agriculture. “And birds under stress are much more prone to disease.”[93]

Birds who remain unsold at the end of the day may go back to nearby farms, taking whatever new viruses they picked up with them.[94] Leading flu researchers Robert Webster and D. J. Hulse wrote, “Highly concentrated poultry and pig farming, in conjunction with traditional live animal or ‘wet’ markets, provide optimal conditions for increased mutation, reassortment and recombination of influenza viruses.”[95] Considering the Hong Kong outbreak and other outbreaks around the world traced to live poultry markets,[96,97] USDA poultry researchers describe live bird markets as the “missing link in the epidemiology of avian influenza.”[98]

Live Bird Markets in the United States

Live bird markets are not limited to Asia.[99] The USDA estimates more than 20 million birds of different species pass through 150 known storefront live bird markets just in northeastern U.S. metropolitan areas every year.[100] In addition, approximately 50 such markets exist in California[101] and a half-dozen in each of the states of Minnesota,[102] Texas,[103] and Florida.[104] Unlike many Asian countries, which have responded to the risks associated with live bird markets by shutting them down, and Hong Kong, which now segregates waterfowl from terrestrial species, U.S. live bird markets are still in operation, and separation of aquatic and land-based birds is not mandated.[105]

Avian Influenza in the United States

Bird flu viruses have been detected every year in the United States since the mid-1960s.[106] In just the last five years, more than a dozen outbreaks of viruses with the potential to mutate into highly pathogenic forms have been discovered.[107]

Prior to the emergence of the H5N1 strain of avian influenza in Hong Kong, the biggest outbreak of bird flu in history was in the United States in 1983—the nation’s most costly and extensive disease eradication. The outbreak of H5N2 avian influenza in Pennsylvania that led to the deaths of 17 million chickens,[108] spread down through Maryland and Virginia,[109] and cost taxpayers and consumers more than $400 million,[110] was considered by some experts to have a link to live bird markets in the northeastern United States.[111] Before then, highly pathogenic bird flu had struck in the 1920s and later occurred in Texas in 2004. Both of these other high-grade bird flu incidents,[112,113] as well as most of the latest U.S. discoveries of low-grade viruses, have also been linked to live poultry markets in the United States.[114]

Highly Pathogenic H5N2 and Live Bird Markets

Investigators speculate that the H5N2 virus responsible for the 1983 outbreak may have initiated in a flock of wild ducks who landed in a pond on a chicken farm in eastern Pennsylvania.[115] Duck feces on the boots of a farmer may have first brought the virus inside a poultry production facility.[116] The virus began benignly, causing drops in egg production and mild upper respiratory symptoms, but soon "rac[ed] though giant commercial chicken warehouses."[117] The now-resident director of the University of Pennsylvania's poultry laboratory explained that "with that many opportunities to mutate under those intensive conditions," the virus evolved from being very mild to one described as "chicken Ebola," causing birds to hemorrhage throughout their bodies.[118]

Robert Webster's team performed genetic analyses of the H5N2 virus before and after it turned lethal, and found the two differed by only a single amino acid. The H5 hemagglutinin protein is more than 500 amino acids long.[119] A tiny point mutation in the viral genetic material changed the 13th amino acid in the H5 chain from an amino acid named threonine to one called lysine—a mutation that, in Webster's words, "change[d] that benign virus into one that was completely lethal."[120] "That such a tiny change in the virus could enable it to wreak so much havoc," Webster and colleagues later wrote, "was an awesome discovery."[121]

The U.S. Department of the Interior's 128-year-old U.S. Geological Survey (USGS), representing the nation's leading governmental authority on the biological sciences,[122] reflected on the evolution of low-grade to high-grade strains of bird flu and echoed other world authorities in implicating industrial poultry practices—not only as providing an "excellent opportunity" for rapid spread (particularly when "poultry are housed at high densities in confined quarters"), but, also for playing in part an "ideal" role in possibly sparking the next human pandemic.[123]

After emerging in 1983, H5N2 resurfaced two years later in low-grade form in Massachusetts, New Jersey, Ohio, and again in Pennsylvania.[124] Its multi-state resurgence was traced back to live poultry markets in New York City. A survey of live markets in 1986 found 48 harboring the virus,[125] suggesting to investigators that live poultry markets may have been the critical mixing point between ducks or geese and chickens that triggered the original Pennsylvania epidemic.[126]

Efforts to purge bird flu viruses from live poultry markets over the years have been unsuccessful,[127] despite periodic quarantine, depopulation, cleaning, and disinfection. In 2004, an outbreak of highly pathogenic H5N2 was discovered in a 7,000-chicken broiler facility in Texas after the owner introduced a chicken from a live poultry market in Houston into his flock.[128] As described by experts at the USDA and the University of Georgia, "[i]n the United States the live-bird markets that are common in some of the large metropolitan areas can serve as a man-made reservoir of influenza virus…."[129]

H7N2 and Human Infections in the United States

In 2002, the United States saw its first human case of bird flu infection. An H7N2 virus caused more than 200 outbreaks in chicken and turkey operations across a mass poultry production area first in Virginia and then into West Virginia and North Carolina, leading to the destruction of almost 5 million birds.[130] H7N2 was identified as a low-pathogenicity virus and was suspected in only one human infection,[131] but genetic analyses show that it is mutating toward greater virulence.[132]

The next year, in 2003, a person was admitted to a hospital in New York with respiratory symptoms and was confirmed to have been infected with the H7N2 bird flu virus. Despite a serious underlying medical condition, the patient recovered and went home after a few weeks.[133] By that year, the virus had swept through millions of egg-laying hens in huge battery-cage facilities in Connecticut and Rhode Island,[134] outbreaks that the industry admits "confirm the vulnerability of egg production units."[135] OIE expert Ilaria Capua describes it as "very difficult" to keep an industrial battery-cage egg facility clean and prevent spread from farm to farm via eggs, egg trays, and equipment. "In our opinion," she told the Fifth International Symposium on Avian Influenza in 2003, "when the infection gets into a circuit, it will spread within that circuit. It finds its way to spread."[136]

H7N2's Spread via Live Bird Markets

The way H7N2 was found to spread in the United States was via live poultry markets. The markets were suspected in the outbreaks in Pennsylvania (1996,[137] 1997, 1998, 2001, and 2002[138]), Virginia (2002),[139] Connecticut and Rhode Island (2003), and Delaware (2004).[140] The Delaware outbreak in a broiler chicken operation confining more than 85,000 birds spread to Maryland before it was stopped with the killing of more than 400,000 birds.[141] In two cases, direct epidemiological evidence links the presence of trucks hauling birds to live poultry markets at affected farms within one week before the appearance of clinical disease.[142] The trucks deliver birds from the farms to the markets, pick up the empty, dirty crates, and then return to the farms. The "most likely scenario," according to USDA scientists, is that the crates or trucks were not completely disinfected of the potential billions of infectious particles present with any gross fecal contamination.[143]

The University of Georgia Southeastern Cooperative Wildlife Disease Study describes the U.S. live poultry market system as an "intricate web of retail markets, poultry auctions, wholesale dealers, and farm flocks." The study notes that in this system, "birds may change hands up to five times before reaching the consumer," increasing exposure and decreasing trackability.[144]

Scientists have watched H7N2 since its emergence in live poultry markets in the United States in 1994. As discussed above, the virus's fail-safe mechanism that prevents it from becoming too dangerous in its natural waterfowl host is the hemagglutinin activation step that limits viral replication to "safe" organs in the body, like the intestine. However, once placed in a land-based host, such as a chicken, viral mutants that can infect all the victim's organ systems may have a selective advantage since easy waterborne spread is no longer possible. H5 and H7 viruses can transform by accruing basic (as opposed to acidic or neutral) amino acids in the hemagglutinin protein cleavage site, where the enzymes of the host activate the virus. Once the virus accumulates approximately five basic amino acids, it may transform from a low-pathogenicity virus to one that is highly pathogenic.

The earliest H7N2 isolates in U.S. live poultry markets in 1994 already had two basic amino acids in the critical cleavage site. By 1998, the virus was up to three. In 2002, H7N2 viruses were found with four, needing only one more slight mutation before the virus could have become deadly.[145] Even though the virus was technically still a low-pathogenic strain, the federal government understood the urgency and danger of the virus's evolution.[146]

Ineffective Virus Eradication of Live Bird Markets

Efforts to eradicate the virus at the source—live poultry markets—have failed. According to the USDA Animal and Plant Health Inspection Service, "Despite educational efforts, surveillance, and increased state regulatory efforts, the number of [virus] positive markets has persisted and increased." In 1998, 30 percent of the markets were infected with H7N2, particularly in the New York metropolitan area. New York has more live markets than all other states in the Northeast combined.[147] By 2001, inspectors could find the virus at 60 percent of markets at any one time.[148]

As the states were failing to control the problem and the virus may have needed only one additional mutation before becoming highly pathogenic, the USDA interceded in 2002, coordinating a system-wide closure of all retail live poultry markets throughout the northeastern United States. Following the mass closure, all birds were sold off or killed, and all markets were cleaned and disinfected, left empty for days, and then repopulated with birds only from closely monitored source flocks confirmed to be negative for all avian influenza viruses. Within five weeks, H7N2 was again found in the live bird markets.

It is unknown whether the virus somehow persisted or was reintroduced. Regardless, despite best efforts at eradication and control, it seems clear that live poultry markets represent a public health risk. Writing in the *Journal of Virology*, USDA researchers concluded that "the rampant reassortment of AIVs [avian influenza viruses] in the LBMs could increase the risk of species crossover because it would increase the chances of the occurrence of the correct constellation of genes to create a virus that replicates efficiently in mammals."[149]

The mass market closure and disinfection did revert the virus's mutation from four to three basic amino acids.[150] Nevertheless, unless all live poultry markets are closed, H7N2 will presumably continue evolving towards a highly pathogenic strain. According to Cornell University's Animal Health Diagnostic Center's virology laboratory director, "It is two major mutations away from becoming a virus that could kill a lot of chickens and become much more pathogenic to people."[151] In 2006, USDA researchers published the results of a study which genetically engineered mutants of an H7N2 virus discovered in New Jersey. They found that the insertion of just a *single* basic amino acid in the right place could transform the virus into a highly pathogenic form.[152] Currently, many suspect that H5N1 is more likely than H7N2 to trigger the next human pandemic, but were it not for H5N1, more attention might be focused on the live poultry markets in New York City—not Hong Kong—to potentially deliver the next avian flu virus with pandemic potential.

Biosecurity: "Wishful Thinking"

Since the primary threat posed by live bird markets is the seeding of industrial poultry operations with virus, the threat could be mediated by meticulous adherence to biosecurity protocols on the farm, such as having all poultry workers, staff, and visitors scrub their footwear in disinfectant every time they stepped into a shed and washing their hands three separate times before entering, as instructed by the USDA's instructional video *Biosecurity: For the Birds*.[153] However, as one North Carolina State University poultry health management professor wrote in an industry trade journal, "high biosecurity and proper monitoring are still wishful thinking in many areas of intensive poultry production."[154]

Increasing intensification of animal agriculture industries has made effective biosecurity less of a possibility. The OIE asserts that the changes in the global poultry industry over the past 20 years make infectious diseases "significantly more difficult to control because of the greater number of susceptible animals reared per given unit of time and to the difficulties in applying adequate biosecurity programmes."[155] The OIE notes that biosecurity measures may be simply incompatible with modern high-density rearing systems.[156] "When an outbreak of avian influenza occurs in an area with a high [poultry] population density," OIE officials wrote, "the application of rigorous biosecurity measures might not be possible."[157] The industry and USDA researchers[158] acknowledge that this is one of the disadvantages of the U.S. system: Not only are 20,000 to 25,000 broiler chickens typically confined in a single shed, but there may be up to 16 sheds at a single facility.[159] There are now egg-laying operations with the capacity to cage more than four million hens in a single complex.[160] When sheds and facilities are situated in close enough proximity to one another, once seeded, the virus may be able to spread through the wind.[161]

Though the U.S. poultry industry claims to have the "best biosecurity system in the world,"[162] academic and governmental investigations have uncovered widespread disregard for biosecurity precautions among both large and small domestic producers.[163] In 2002, University of Maryland researchers sent questionnaires about biosecurity practices to commercial broiler chicken facilities throughout the Delmarva Peninsula, where more than 100 million chickens raised for meat of various ages are at any given time. Fewer than half the facilities returned the survey, and those that did admitted to severe lapses in biosecurity. The researchers concluded that U.S. broiler chicken flocks "are constantly at risk of infection triggered by poor biosecurity practices."[164]

Charles Beard, acting as U.S. Poultry and Egg Association vice president, admitted that relying on biosecurity measures to protect the U.S. poultry industry "could appear naïve."[165] "After all, biosecurity is mostly a 'people' thing." Even putting aside human fallibility, Beard is concerned that unless all poultry workers "join in with conviction and enthusiasm, it is not likely to be successful" regardless of what "those in charge" say.[166] The University of Maryland surveys show biosecurity "enthusiasm" to be lacking, and the "convictions" of poultry corporations like Tyson have leaned more toward 20 felony violations for illegal dumping of untreated wastewater into the nation's rivers[167] than toward a desire to practice biosecurity. In fact, Tyson Foods, the largest chicken-producing corporation in the world,[168] found itself before the Supreme Court in 2005 for refusing to pay workers for time spent donning protective clothing at a poultry plant. The Supreme Court ruled unanimously against Tyson.[169]

Breaches in biosecurity occur in modernized facilities around the world.[170] The European Food Safety Authority recognizes that when this happens in a densely populated poultry area, these breaches can result in "massive spread."[171] According to animal disease control experts, biosecurity measures are costly for the industry[172] and "not easy to sustain in the long term."[173] Emeritus veterinary poultry professor Simon M. Shane, author of the Handbook on Poultry Diseases, notes a "decline in the standards of biosecurity in an attempt to reduce costs in competitive markets." The decline is a contributing factor, Shane concludes, in the frequency and severity of disease outbreaks.[174]

In *Poultry Digest*, longtime industry and avian health expert Ken Rudd wrote "Poultry Reality Check Needed," in which he laid out in stark terms the industry's skewed priorities: "An examination of virtually all the changes made in the past decade shows that they've come in the guise of convenience and efficiency, but they are, in fact, cost-cutting measures. Few, if any, decisions have been made solely for the sake of avian health or the long-term protection of the industry. The balance between the two has been lost; the scale is now weighted almost entirely on the cost-cutting side. And, therefore, on the side of microorganisms—much longer on this earth than humans![175]" Specifically, Rudd criticized the profitable yet risky practice of reducing the duration of downtime between flocks and the trend of not cleaning poultry houses between flocks, and pleaded with his industry to "consider the cost of catastrophe."[176]

Examining other widespread viral disease outbreaks, like foot and mouth disease in Europe, the vulnerability of modern animal agriculture is exposed.[177] In the United States, within three years of the emergence of the highly virulent "Delaware variant" of the immunodeficiency infectious bursal disease (IBD) virus, virtually the entire broiler chicken industry east of the Mississippi was affected.[178] The United States, the country that pioneered industrialized poultry production, has reported more bird flu than any other country in the world.[179]

The Virginia outbreak in 2002 that led to the deaths of millions of birds and found its way onto hundreds of farms highlights the fallacy of protection in the United States by biosecurity. Based on the rapid domestic spread of bird flu in 2002, leading USDA poultry researchers have concluded the obvious: "[B]iosecurity on many farms is inadequate."[180] The situation has not necessarily improved since then, according to Yvonne Vizzier Thaxton, executive editor of *Poultry* magazine and professor of poultry science at Mississippi State. In 2005, she editorialized that "I believe it is time to reexamine biosecurity in our industry. We've become lax in many ways, and this is exactly what it took to get the 1983 AI outbreak moving…If WHO is right and a pandemic brings human AI to the United States, will you be able to look your family and neighbors in the eye and say you've done all you can to stop the spread? Having to answer that question alarms me!"[181]

Closing Down Live Bird Markets in Asia

H5N1 is considered a Biosafety Level 3+ pathogen,[182] meaning that, in a laboratory setting, the virus is only to be handled in unique, high-containment buildings specially engineered with air locks, controlled access corridors, and double-door entries. Access is limited to competent personnel with extensive training,[183] and showering is required upon each entry and exit.[184] Air flow is ducted for unidirectional, single-pass filtered exhaust only.[185] All floors, walls, and ceilings are waterproofed and sealed with continuous cove moldings.[186] All wall penetrations, such as electrical outlets and phone lines, are caulked, collared, or sealed to prevent any leaks.[187] Surfaces are disinfected on a daily basis,[188] and solid wastes are incinerated.[189] "Unfortunately," leading USDA poultry virologist Dennis Senne told an international gathering of bird flu scientists, "that level of biosecurity does not exist in U.S. poultry production and I doubt that it exists in other parts of the world."[190]

Recognizing both the seriousness of the public health threat and the impracticality of absolute biosecurity, governments throughout Asia are phasing out these markets. China has set the precedent of attempting[191] to ban all live bird markets in Shanghai, its largest city, as well as the capital city of Beijing.[192] Hong Kong has also decided to phase them out,[193] and the Chinese government has reportedly urged all large cities to "gradually call off the killing and sales of live fowls in the market."[194] Similarly, bans have reportedly been proposed in Singapore, Japan,[195] and Vietnam's Hanoi, Hai Phong, Vinh and Ho Chi Minh City.[196] Starting in 2008, those found publicly slaughtering birds in Taiwan may face a 500,000 NT fine (approximately $15,000 USD).[197] Though there has never been a recorded outbreak in Taiwan, the chairman of its National Science Council explained the reasoning behind the ban: "We can't foresee whether an outbreak of bird flu will happen in Taiwan, but every nation in the world is obligated to take part in the prevention of the epidemic."[198]

There has been support from the scientific community for the transition from live markets to supermarkets. Paul Chan, for example, a professor of microbiology at Chinese University of Hong Kong, told the *China Daily*, "I support doing away with selling live poultry altogether."[199] In light of the emergence of SARS and H5N1 from live animal markets in Asia, a 2006 scientific review concluded that "the most optimal strategy is to forbid all kinds of live animals at wet-markets, with enforcement of central slaughtering."[200]

Robert Webster, the world's authority on avian influenza and chair of the Virology Division of St. Jude Children's Research Hospital in Tennessee and director of the U.S. Collaborating Center of the WHO, believes that even with all Hong Kong live markets closed, the overall pandemic risk may not be sufficiently affected unless live markets could be closed throughout China and elsewhere.[201] Webster's team has concluded, "Until the traditional practice of selling poultry in the live market changes we will have to accept that live markets are breeding grounds for influenza viruses…."[202]

Live Bird Markets Should Be Shut Down Throughout the United States

Though suspected of playing a pivotal role in the spread of bird flu in the United States,[203] live bird markets in this country are proliferating. In New York City, for example, the number of live bird markets almost doubled from 44 in 1994 to more than 80 in 2002.[204] Given the risk, many in the U.S. commercial poultry industry are "absolutely determined" to have live markets eliminated, according to a Louisiana State University poultry scientist.[205] Briefly but incisively, the president of the USA Poultry and Egg Export Council commented, "We can't jeopardize the entire U.S. [poultry] industry."[206]

According to the USDA's Agricultural Research Service, "The U.S. currently has the largest, most genetically homogeneous and, thus potentially, the most disease-susceptible population of food animals in the history of mankind….The emergence of a new disease or a slight shift in the epidemiology of an existing disease could lead to immediate and disastrous results for American livestock producers and consumers."[207]

The USDA agrees that live bird markets have been shown to present a "major risk" to the nation's poultry industry.[208] Agency scientists wrote that "live bird markets of the Northeast remain the biggest concern for the presence of avian influenza in the United States."[209] Yet, despite agreement by both the industry and the USDA, live bird markets persist and indeed flourish. Some industry officials fear that closing bird markets would drive the entire trade underground, making it even more difficult to regulate.[210] After the SARS outbreak, for example, customer demand in Asia drove the cost of civet cats up to $200, making it likely that such animals could be obtained regardless of legality.[211] The USDA has therefore chosen to "manage or mitigate the risk rather than to outlaw it."[212]

By its own admission, the USDA is doing a poor job of risk management. Speaking at the Fifth International Symposium on Avian Influenza in 2002, USDA poultry researchers said, “Considerable efforts are continuing on the part of industry and state and federal governments to control influenza in the LBM system, but currently the efforts have been unsuccessful.”[213] “Despite educational efforts, surveillance, and increased state regulatory efforts,” the USDA admitted the following year that “the number of [bird flu] positive markets has persisted and increased.”[214] Live bird markets seem inherently risky. In response to virus isolations from New Jersey’s markets, the state veterinarian said, “They can be doing everything right and still have a market that tests positive.”[215]

Even if a segment of the live bird trade was forced underground, the situation and risks might not significantly worsen. Record-keeping in live poultry markets is already sparse or nonexistent even as to the birds’ country of origin.[216] Currently, the purchase and sale of live birds is a cash business in which market owners are “disinclined to keep accurate records that would be costly if subjected to IRS scrutiny.”[217] A 2003 survey of handling practices at live bird markets found that fewer than 2 percent of suppliers followed the recommended biosecurity practices to prevent the spread of the disease.[218] USDA Science Hall of Famer[219] Charles Beard is concerned that U.S. live bird markets could be the portal by which H5N1 enters commercial poultry flocks in the United States.[220]

Live bird markets continue to exist in the United States only because local health authorities continue to license them. They are exempt from federal meat inspection laws because they slaughter fewer than 20,000 birds a year,[221] an exemption that doesn’t apply for other animals.[222] Poultry specialists predict that if live bird markets had to be held to the same federal standards of inspection, cleanliness, and pathogen control as the commercial poultry industry, or small producers of other animals, “authorities could virtually eliminate LBMs.”[223]

Currently, all regulation of live markets, including licensing and inspection, is done at a state level and, as such, represents a patchwork with some states having little or no intact regulatory apparatus. To remedy the situation, in October 2004 the USDA released a guidance document with uniform standards for regulation, suggesting quarterly testing and temporary market closure and disinfection if H5 and H7 AI viruses are discovered. By 2006, the USDA asserted they had Memorandums of Understanding from all high-risk states, promising to move toward these standardized guidelines. In exchange, the states receive federal funds, resources, and assistance from staff, if needed, to carry out their oversight of the markets. As a result of increased surveillance, the number of markets found to be positive for AI viruses is reportedly in decline.[224] However, despite these efforts, experts at the USDA and the University of Georgia concluded in a 2006 review that U.S. live bird markets remain “an ideal environment for transmission, adaptation and evolution of avian influenza viruses.”[225]

The regulatory strategy of increased surveillance and disinfection was developed at a time when avian influenza was only known to affect birds. With knowledge that these viruses can kill people directly, can escape into the environment and, in fact, were the source of the 1918 pandemic—the worst plague in human history—the United States must follow Asia’s example and shut down these markets.

The authority conferred upon the Secretary of Health and Human Services by Title 42 United States Code Section 264 to prevent the introduction, transmission, and spread of communicable diseases in the United States could be used to close live bird markets across the country. Just as the Food and Drug Administration banned the sale of small turtles for pets in 1975 to prevent the spread of *Salmonella*, it (or another appropriate agency, such as the Centers for Disease Control and Prevention) should be able to ban the sale of birds at live bird markets to prevent the spread of avian influenza.

On January 3, 2007, New York City Assemblywoman Barbara Clark introduced NY A.B. 246, which would prohibit the licensing of new establishments that slaughter animals within 25 feet of a residential dwelling in a city with a population of one million or more. This would effectively outlaw any new live bird markets in New York City, where markets and their public health risks remain most concentrated.

Conclusion

In a 2004 consultation document for the government, the University of Hong Kong School of Public Health explained what was at stake: "The trade-off between the preference for eating the flesh of freshly slaughtered chicken and the risk to local, regional, and global population health from avian influenza should be addressed directly, and in terms of a precautionary public health approach aimed at providing the greatest benefit to the maximum possible number of people."[226] The United States government should follow suit and find that the risks of live bird markets far outweigh justifications for their existence.

Dr. Webster concluded a landmark article on the emergence of pandemic strains of influenza with these words: "An immediate practical approach is to close all live poultry markets…." He notes that with refrigeration systems widely available—even through much of the developing world—it is no longer necessary to sell live birds. "The reality is that traditions change very slowly," he said, but "a new pandemic could accelerate this process."[227] There is a tendency not to "shore up the levies" until after disaster strikes, but by acting now to close live bird markets in the United States, the global risk of the future emergence of flu viruses with pandemic potential may be reduced.

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